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CHARGED PARTICLE LET-SPECTRA MEASUREMENTS ABOARD LDEF

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SUMMARY

The linear energy transfer (LET) spectra of charged particles has been measured in the 5-250 keV/μm (water) interval with CR-39 and in the 500-1500 keV/μm (water) interval with polycarbonate plastic nuclear track detectors (PNTDs) under different shielding depths in the P0006 experiment. The optimal processing conditions were determined for both PNTDs in relation to the relatively high track densities due to the long-term exposure in space. The total track density was measured over the selected samples, and tracks in coincidence on the facing surfaces of two detector sheets were selected for measuring at the same position on each sheet. The short range (SR) and Galactic Cosmic Ray (GCR) components were measured separately with CR-39 PNTDs and the integral dose and dose rate spectra of charged particles were also determined. The high LET portion of the LET spectra was measured with polycarbonate PNTDs with high statistical accuracy. This is a unique result of this exposure due to the low flux of these type of particles for typical spaceflight durations. The directional dependence of the charged particles at the position of the P0006 experiment was also studied by four small side stacks which surrounded the main stack and by analyzing the dip angle and polar angle distributions of the measured SR and GCR particle tracks in the main stack.

INTRODUCTION

In the past a series of cosmic ray radiation dosimetry measurements — including charged particle measurements — has been carried out both by Americans and Soviets (ref. 1). These measurements were usually performed on short term flights and with changing orientations of the spacecraft and detectors during the flights. The unique features of the LDEF mission, such as the very long duration time (2115 days) in space and the fixed gravity orientation, provide

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excellent opportunities for dosimetric experiments on LDEF. For example plastic nuclear track detectors (PNTDs) can measure the high LET-tail of the LET (linear energy transfer)-spectra with superior statistical accuracy and can determine the directional dependence of cosmic ray particles as well as of their secondaries.

The Physics Department of the University of San Francisco in collaboration with the NASA-Marshall Space Flight Center has carried out several space radiation dosimetry measurements aboard LDEF. Data from experiments at different positions on the orbiter can be correlated. The unification of the results should provide accurate cumulative exposures of the LDEF orbiter from different directions. Early results of these experiments are discussed by Benton et al. (ref. 2). In this paper we present preliminary results obtained by evaluating PNTD sheets from one of the major dosimetric experiments (P0006) on LDEF. The heavy cosmic ray charged particles detected with PNTDs have a high quality factor and the ability to produce special effects in biological samples and single event upsets in microelectronic circuits which underlines their importance especially in long duration flights.

EXPERIMENTS

Experiment P0006 on LDEF contained a stack of passive integrating detectors to measure different components of the accumulated radiation exposure on the LDEF. It includes stacks of different kinds of PNTDs and thermoluminescent detectors (TLDs) designed to measure the variation of LET spectra of cosmic ray charged particles and the total absorbed dose as a function of shielding depth. Activation foils for neutron and proton fluences, fission foil detectors also for neutrons and muscovite mica for heavy HZE particles are also included.

The structure of the detector stack, showing the major components, is given in Figure 1. Of the 9 central stack modules, the upper 8 contain PNTDs in separate arrays. The PNTDs used were pure CR-39, CR-39 with DOP, Tuffak and Sheffield polycarbonate and Melinex polyester. Initial studies have been conducted with CR-39 and Sheffield polycarbonate.

The high sensitivity CR-39 (USF-4, University of San Francisco) track detectors were used to measure the LET-spectra in the 5-250 keV/μm (water) interval.The standard technique normally used with space flight materials had to be modified because of the very high track densities obtained in these samples due to the long-term exposure in space. Hence shorter etching time (36 hrs at 50°C in 6.25 N NaOH, which corresponds to about 10 μm removed layer) and higher magnification ($\times$600) for scanning and measuring of these samples has been applied. Detector saturation, due to track overlapping, would occur for the normal processing time of 168 hrs (40 μm). For the measurement of the high LET-tail of the LET-spectra the Sheffield polycarbonate was used. Although the track density in this detector was found to be much lower than in CR-39 (due to the lower sensitivity of this detector) the optimal etching time was found to be even shorter than in the case of CR-39. This is because the majority of the tracks in this detector are formed by short range secondary particles which are over-etched after a few micron-thick layer is

removed. Even after a 4 μm removed layer — applied in our study — about half of these tracks were found to be overetched. This means that information about charge, energy and LET of the particles which can be obtained from the measured etched pit diameters is limited.

In both CR-39 and polycarbonate measurements the coincidence method of track detection has been used. Processed sheets were reassembled as pairs in their original flight orientations. The doublets mounted on the microscope stage were scanned at the inner adjacent surfaces and tracks in coincidence were selected for measuring. Tracks at one surface are neglected because they do not contribute to the flux of charged particles present at the pre-etched surfaces of the track detector sheets. In the case of CR-39 PNTDs detected events were then separated into long range (the particle left tracks on all four surfaces of the doublet) or short range (the particle left tracks on the two inner surfaces or the two inner and one outer surface). The short range (SR) particles are usually due to stopping primary protons (mainly trapped) or to secondaries from target nuclei in the CR-39.

The track parameters were measured at the upper of the two adjacent surfaces and particle LET was calculated using the measured detector response curves. Integral and differential LET-spectra for flux, dose rate and dose equivalent rate were then generated.

RESULTS AND DISCUSSION

LET-spectra Measurements

The integral LET-spectra — measured with CR-39 track detectors — in the main stack and in the side stacks A and B are presented in Figure 2. The shielding depth in the main stack was 6.5 g/cm^2 and 0.5 g/cm^2 in the case of the side stacks. Side stacks A and B, however, were facing to different directions (see Figure 1), hence the difference in the LET-spectra measured by these detectors can be explained by the directional dependence of the charged particle radiation field at the position of the P0006 experiment.

Figure 3. shows the high LET-tail of the LET-spectra measured by Sheffield polycarbonate PNTDs in the main stack of P0006 at two different shielding depths. Most of the tracks measured in polycarbonate were found to be rounded on both the second and third surfaces of the detector doublet. These tracks are formed by short range secondary particles, when the total trajectory is fully etched out for both directions. Primary particles usually produce double pointed or a pointed and a rounded track at the adjacent surfaces. About half of the tracks look like small bubbles, which means that the trajectory of the particle was completely within the bulk layer removed during the etching process. The etch rate ratio and LET value which are obtained for these tracks (from the measured diameters of the tracks) usually underestimate the real value. Also the size of these tracks is very small and the scanning efficiency is less than optimum. For these reasons the reliability of LET-spectra obtained with polycarbonate detectors is better for values of LET$\geq$600 keV/μm. The relatively low sensitivity of this material also suggests

that these tracks are probably formed by ions heavier than alpha particles. An interesting and important observation is that the flux of the particles in the 800-1200 keV/μm region does not depend on the shielding depth of the evaluated samples. Measurements with higher shielding depths are in progress.

Some of the problems mentioned above can be compensated for by using two or multiple step etching. The advantage of this technique is higher accuracy of LET measurement at the adjacent surfaces and a possible charge and energy determination of short range recoils. The application of the approximately tissue equivalent PNTDs to perform this kind of measurement is also unique because the LET, charge and energy distribution of heavy recoils depends on the chemical composition of the target material, which in the case of PNTDs is the detector material itself. If a material other than PNTD is used, the recoils will differ. The ideal detector for this study would be a tissue equivalent detector, with dimensions equal to at least the average range of heavy recoils. To measure the LET value or to identify the particle, however, we need local information along the particle trajectory.

Directional Dependence

The contour of the surface openings of etched particle tracks can usually be considered to be elliptical. From the measured diameters of the ellipse it is possible to calculate the dip angle (the angle between the trajectory and the surface of the detector) and from the orientation of the ellipse the azimuthal angle of the particles. The dip angle distribution of measured particles is strongly modified by the detection efficiency of the detector, that is, particles with low LET can be detected only at high dip angles (close to normal incidence). The azimuthal angle measurement is also limited. Tracks of particles close to normal incidence and those over-etched into the spherical phase are circular, hence the azimuthal angle cannot be determined. Another problem is that the direction of movement of the particle along the trajectory is not always known. This means that the azimuthal angle can be determined to the extent of a rotation by π. In our azimuthal angle measurements we assumed that all the particles were moving into the stack and none out of it. Figures 4 and 5 show the azimuthal angle distribution of GCR particles (measured with CR-39) and short range secondary particles (Sheffield polycarbonate) in the main stack of P0006 experiment. (The orientation of P0006 experiment on the LDEF is not yet confirmed.)

Although there are some limitations in studying the azimuthal angle distribution of cosmic ray charged particles, the results presented here clearly indicate that there is a strong directional dependence both of GCR and secondary heavy ions. These effects are probably related to the effect of the Earth's magnetic field and the anisotropy of trapped protons.

CONCLUSIONS

Initial results of the P0006 experiment show that:

- The LET-spectra of cosmic ray charged particles depend on the orientation of the PNTD stack.
- The high LET-tail of the LET-spectra does not change significantly with the shielding depth.
- There is a significant directional dependence of both GCR and short range secondary heavy ions.

The preliminary results of P0006 experiment show that the LDEF mission provided a unique and unprecedented opportunity to gather data on the space radiation environment in low earth-orbit. The collection of more comprehensive experimental data and its detailed analyses will be invaluable in addressing the numerous issues concerning the ionizing radiation environment in space and its impact on manned and unmanned space missions.

REFERENCES

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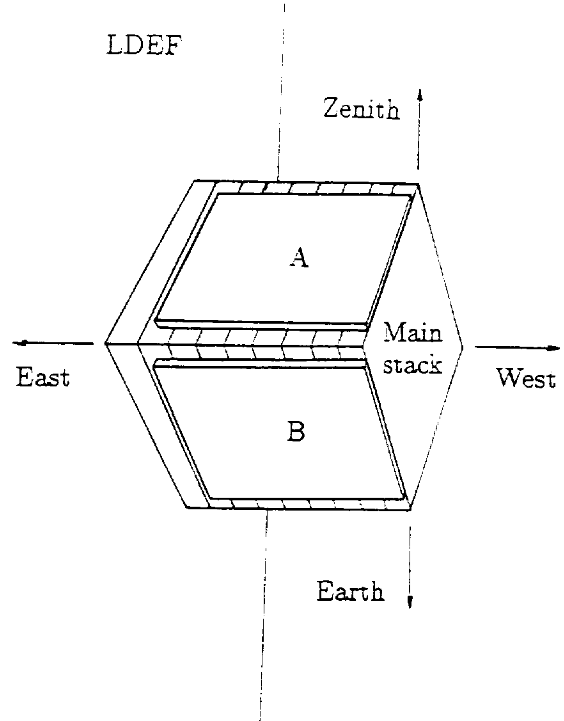

Fig. 1. The major structure of P0006 and its position on the LDEF.

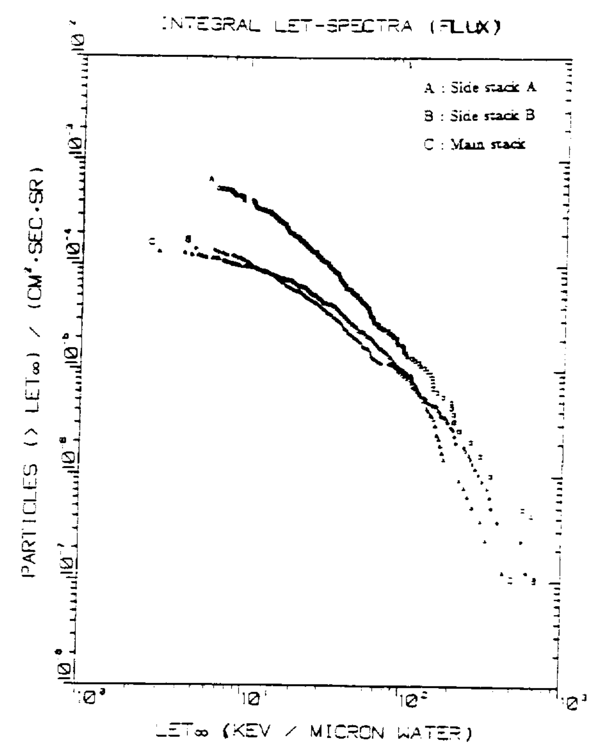

Fig. 2. Integral LET-spectra measured in the main stack and in the side stacks A and B of P0006 experiment with CR-39 PNTDs. The main stack was facing to the west and side stacks A and B were facing approximately to the space and Earth, respectively, in the F2 tray of the satellite.

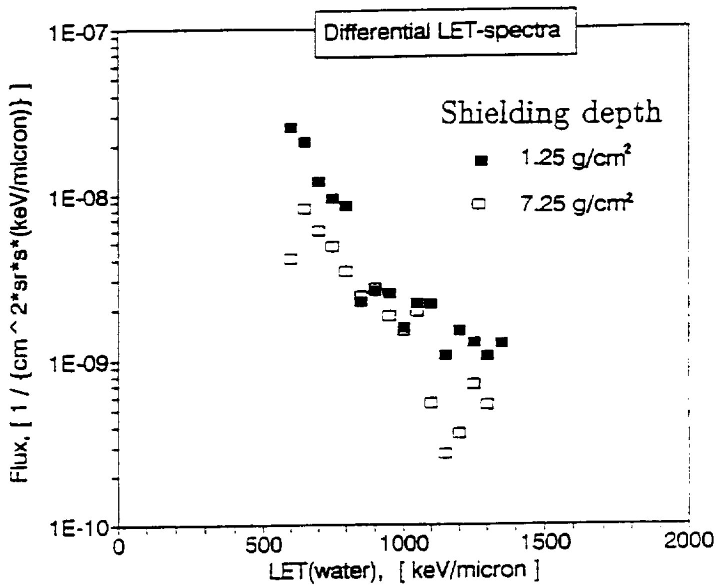

Fig. 3. The differential LET-spectra measured with polycarbonate PNTDs at different shielding depths.

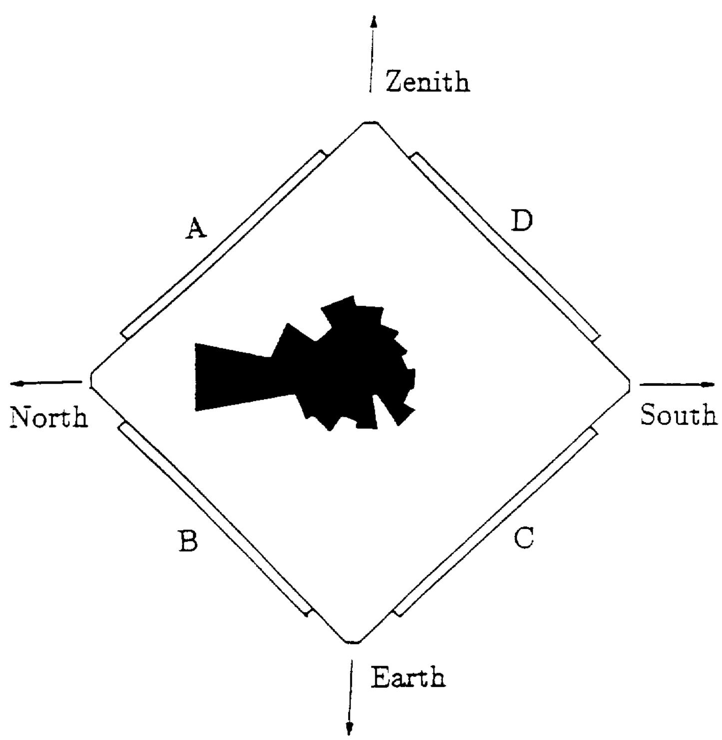

Fig. 4. Azimuthal angle distribution of GCR particles in the main stack of P0006 experiment on LDEF. All particles were assumed to arrive from the direction of space.

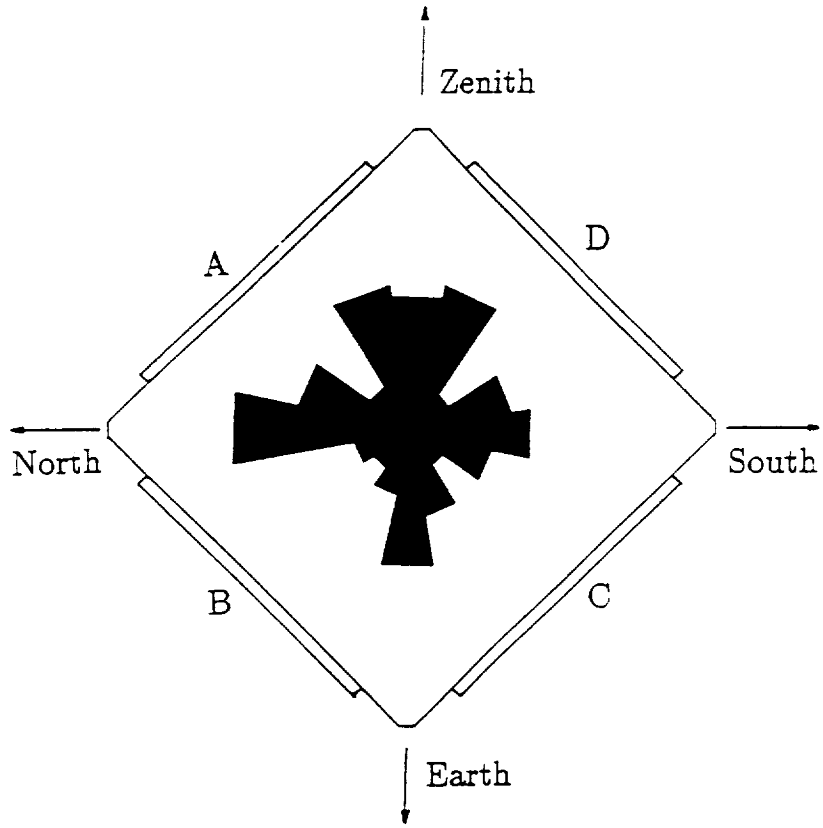

Fig. 5. Azimuthal angle distribution of short range secondary heavy ions in the main stack of P0006. (Sheffield polycarbonate measurement.)